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AN EXPERIMENTAL APPROACH FOR THE EVALUATION OF VOCAL BEHAVIOR OF UNIVERSITY PROFESSORS

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ABSTRACT[*]

Voice risk factors for teachers were widely investigated, since this professional category is mainly subjected to vocal diseases. However, the existing literature focused on kinder-garden, primary and secondary school-teachers. In this study, the attention is towards the vocal behavior of university professors, who hold lessons in large classrooms, talk continuously for long time intervals and often use microphone to improve their intelligibility. An experimental campaign has been planned that involves subjects that teach in classrooms with different volume, reverberation-time and background-noise. The voice monitoring is performed using the Vocal Holter device, a portable vocal analyzer developed at Politecnico di Torino. The material collected for each professor includes a sustained vowel /a/, a comfortable free-speech (about 5 minutes), two lessons (max. 3 hours). The parameters extracted from the sustained vowel allow a preliminary vocal status of each subject to be assessed, while the free-speech parameters represent the baseline with respect the lesson parameters are compared to. A first pilot study has been carried out that involved 14 subjects that taught in 13 different classrooms. Results are reported in terms of vocal parameters and their correlation to classroom acoustical characteristics. Examples of parameters are jitter, shimmer and CPPS (sustained vowel), sound pressure level, fundamental frequency and duration of voice and silence periods (lessons).

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1. INTRODUCTION

Teachers of any grade belong to the professional category that most suffer from voice disorders, due to continuous use of voice as primary working tool [1]. A wrong and overemphasized use of the voice could cause the occurrence of vocal pathologies that may have from light to severe consequences, e.g., weak voice, throat, aphonia, nodules and polyps [1,2]. Prevention actions should be promoted through the monitoring of the vocal behavior repeatedly during working hours and especially in real working conditions, as many studies proved that the acoustic characteristics of the environment in which voice is used have a strong effect on its use [3,4].
Indeed, recent studies proved that the acoustic characteristics of classrooms strongly influence the voice use of teachers [5-8]. The main outcomes of these studies agree on similar considerations. Reverberation time should vary around an optimal value of 0.75 s at mid-frequencies to support voice production, as both lower and higher values would require a teacher to increase her/his vocal effort (i.e., the sound pressure level measured at 1 m from the mouth [9]) in order to be heard [5-7]. In the case of lower reverberation time, teachers rise their voice due to the lack of voice support from the room, while in the case of higher reverberation time it is supposed that they rise their voice due to the amplified background noise. Noise levels should be reduced, especially when primarily generated by sound sources inside the classroom (e.g., students talking and moving in the classroom [10]), to diminish the

occurrence of negative consequences on voice due to the Lombard reflex, which is known as the increase in voice level due to increasingly noisy conditions [11]. Sato and Bradley [12], an increase of voice level of 0.72 dB per 1 dB of increase of noise level was found during working hours in teachers.
Therefore, the need to monitor voice use in field emerges. Research has focused on of the development of voice monitoring procedures through the use of wearable devices [13,14], which are based on appropriate calibration and uncertainty evaluation procedures for the estimation of voice parameters with high accuracy [15,16,17] and that are also accurate in the estimation of parameters related to voice diseases [18]. However, there is still need to widen research on the relationship between classroom acoustics and the vocal effort of teachers, especially for what concerns university classrooms. This is particularly needed because the effects that classroom acoustics has on voice production is still not fully explored due to (i) differences in the dimensions and architectural characteristics of university classrooms that typically imply the use of PA systems [19] and to (ii) the teaching task at university level in terms of duration and repetition in a longitudinal observation (e.g., long lessons that are similar to monologues repeated for 2-3 times a week).
This work focuses on defining a methodology aimed at:

- detecting the presence of vocal diseases in university professors who underwent a repeated vocal monitoring during their lessons;
- establishing possible warning scores to be assigned to the monitored lessons in order to alert the occupational health service of the university whether it would be worth providing support for the reduction of the related occupational risks;
- understanding whether the measured voice parameters depend on classroom acoustics;
- analyzing the differences in voice production of university professors during the working activity with respect to a conversational activity.

2. METHODOLOGY

The present activity was carried out during six weeks in April-June 2022 and involved i) the acoustic characterization of university classrooms, ii) the vocal monitoring of professors, iii) the analysis of vocal parameters and classroom acoustics, preceded by the selection of the classrooms based on their volume and the recruitment of professors who had teaching activities in those classrooms.

2.1 University classroom selection and acoustic parameters

All the selected classrooms are located in the headquarters of the Politecnico di Torino. Firstly, a range of classrooms was selected based on their volume, with the aim of carrying out the activity in classrooms that had volumes covering a wide range (see Tab. 1). Another important selection criterion was related to the presence or absence of acoustic treatment, to have a sample of lessons monitored in good acoustic conditions and a sample monitored in non-good acoustic conditions. After the individuation of the classrooms, professors that had teaching activities in these were recruited on a voluntary basis. This resulted in a total of 13 classrooms with volumes ranging from about 197 m^3 to 1115 m^3. In each classroom the optimal reverberation time ($T_{20,opt}$), the measured reverberation time (T_{20}) and the background noise level (BNL) were defined.

Table 1. Classroom identification code (C), floor in the building (F), number of seats (N), area (A), average height (h), volume (V), acoustic treatment (tr) are shown.

C	F	N	A [m^2]	h [m]	V [m^3]	tr
2T	ground	120	142.9	7.80	1114.9	No
8C	second	193	223.9	4.58	1025.7	No
2P	ground	220	218.4	4.50	982.9	Yes
3P	ground	220	218.4	4.50	982.9	Yes
9T	ground	144	132.1	6.35	838.8	No
1B	first	196	240.2	3.30	792.5	No
4N	ground	144	133.3	5.2	692.9	No
R4B	first	150	141.5	4.24	600.0	Yes
5S	basement	156	163.1	3.25	580.0	Yes
2I	basement	87	109.6	3.20	350.7	No
13B	first	51	82.9	3.50	290.1	No
5N	ground	68	69.7	3.40	236.9	No
2N	ground	139	138.0	2.85	196.7	No

2.2 University professors' voice monitoring

A total of 14 professors (9 males and 5 females) in an age range between 34 and 68 years old answered the recruitment email. Details of the professors and of their lessons monitored are shown in Tab. 2.

Table 2. Professors' identification code (ID) with gender indication (M=male, F=female), age and

lessons details, i.e., classroom and duration in minutes of the lesson.

ID	Age	Lesson 1		Lesson 2	
		Classroom	Duration	Classroom	Duration
00M	56	4N	90	5N	90
01F	45	8C	180	8C	180
01M	34	1B	180	1B	90
02F	54	13B	90	-	-
02M	62	R4B	180	R4B	180
03F	40	9T	90	9T	90
03M	46	5S	90	5S	90
05M	68	5N	90	-	-
06F	64	3P	90	3P	180
06M	45	2P	90	2P	180
07F	53	2T	180	-	-
07M	63	5S	90	5S	90
08M	46	2N	180	2N	90
09M	43	2I	90	2I	90

The voice monitoring was performed through the use of the Vocal Holter, a portable vocal analyzer developed at Politecnico di Torino, which consists of a contact microphone that is worn around the neck and detects the vibrations induced by the vocal folds during phonation periods. Four different monitoring were done for each professor:

- a vowel /a/ at different levels;
- a sustained vowel /a/ for a time interval between 6 s and 12 s;
- a comfortable free speech (about five minutes);
- two lessons (90 min or 180 min).

The vowel /a/ vocalization at increasing level was used for the calibration of the device needed to estimate the sound pressure levels from the voltage signals detected at the base of the neck, and is done having a calibrated air microphone at 22 cm distance from the mouth. On the other hand, the local jitter, the local shimmer, the $CPPS_{mean}$ (Cepstral Peak Prominence Smoothed mean) and the $CPPS_{std}$ (Cepstral Peak Prominence Smoothed standard deviation) were extracted from the sustained vowel /a/ for a preliminary analysis of the vocal status of each professor. Furthermore, a warning score was defined related to the conditions of the professor's phonatory apparatus.

The comfortable free-speech was monitored to have a baseline, that is a vocal comfort condition of each subject and is used for the comparison with the parameters obtained from the two lessons, during which professors tend to increase their vocal effort. The analyzed parameters are the equivalent sound pressure level (SPL_{eq}) the fundamental frequency (f_o) and the duration of voicing time percentage (D_t%).

3. RESULTS

3.1 Occupational risk

The parameters returned by the device Vocal Holter for the sustained vowel /a/, which are local jitter (%), local shimmer (%), mean and standard deviation of the Cepstral Peak Prominence Smoothed (CPPS, dB), are processed in order to evaluate a warning score for each involved subject. Such a warning score is conceived as a priority level from an occupational-risk point of view, and it is assigned as described below.

For the parameters local jitter and local shimmer, the literature provides cut-off values that distinguish healthy from pathological voices, but there is no full agreement among different authors. For this reason, starting from the results provided in [20,21], the contribution of jitter and shimmer to the warning score are assigned according to the following rule:

- -1 if jitter < 0.31% (shimmer < 2.37%), which identifies a healthy voice;
- +1 if jitter > 0.43% (shimmer > 2.55%), which identifies a pathological voice;
- 0 if jitter is in the range (0.31÷0.43)% and shimmer is in the range (2.37÷2.55)%, thus considering these ranges as not reliable.

A similar rule is implemented for the parameters $CPPS_{mean}$ and $CPPS_{std}$ [18,22]:

- -1 if $CPPS_{mean}$ > 19.7 dB ($CPPS_{std}$ < 0.9 dB) for a healthy voice;
- +1 if $CPPS_{mean}$ < 18.0 dB ($CPPS_{std}$ > 1.3 dB) for a pathological voice;
- 0 if $CPPS_{mean}$ is in the range (18.0÷19.7) dB and $CPPS_{std}$ is in the range (0.9÷1.3) dB (not reliable evaluation).

Implementing the described rules, the warning scores summarized in Tab. 3 are obtained, where a yellow background color identifies a parameter that corresponds to a pathological voice, a green background color identifies a healthy voice parameter, and a white background color refers to an unreliable evaluation. The last column reports the obtained warning score, which is included in the range (-4 ÷ +4): special care has to be paid towards the subjects with positive values, such as 01M and 05M (+4) and 06F (+3).

Table 3. Evaluation of the warning score according to the sustained vowel /a/ parameters. Yellow background color: pathological voice; green background color: healthy voice; White background color: unreliable evaluation.

ID	Parameters vowel /a/				Warning score
	jitter (%)	shimmer (%)	$CPPS_{mean}$ (dB)	$CPPS_{std}$ (dB)	
00M	0.26	2.63	19.5	1.1	**0**
01F	0.21	1.38	17.3	0.7	**-2**
01M	0.82	2.61	17.8	2.6	**+4**
02F	0.34	1.61	18.2	2.1	**0**
02M	0.33	1.70	18.8	1.0	**-1**
03F	0.29	1.20	18.0	1.7	**-1**
03M	0.32	2.99	17.4	1.2	**+2**
05M	0.47	3.34	16.9	1.7	**+4**
06F	0.47	2.89	16.3	1.1	**+3**
06M	0.31	1.59	19.2	1.2	**-1**
07F	0.28	1.17	18.7	1.1	**-2**
07M	0.31	2.90	18.5	1.2	**+1**
08M	0.21	1.34	18.0	0.8	**-3**
09M	0.23	1.35	19.3	0.8	**-3**

3.2 Acoustic parameters vs classroom acoustics

About the acoustic characteristics of the classrooms where the professors have been monitored, the measured reverberation time T_{20} (s) has been considered as the most important qualifier. For this reason, the measured values $T_{20,meas}$ have been compared to optimum values $T_{20,opt}$, obtaining the results that are summarized in Tab. 4. In the same table, the column "ΔT_{20} (s)" refers to the difference between measured and optimum values, while the column "JND+Unc. (s)" represents the minimum value that is considered meaningful to qualify a classroom according to the obtained value of ΔT_{20}, where JND is the Just Noticeable Difference and Unc. is the measurement uncertainty of $T_{20,meas}$. According to the obtained results, a classroom is qualified as good (green background colour in Tab. 4) from an acoustic point of view if the absolute value of ΔT_{20} does not exceed JND+Unc.; on the contrary, a classroom is qualified as bad (yellow background colour in Tab. 4). One should note that the classroom 8C has not been evaluated due to inaccessibility for maintenance reasons (grey row in Tab. 4).

Table 4. Classroom classification according to the measured reverberation time T_{20} (s).

C	$T_{20,meas}$ (s)	$T_{20,opt}$ (s)	ΔT_{20} (s)	JND+Unc. (s)
2T	2.88	0.99	+ 1.89	0.15
8C	n.a.	n.a.	n.a.	n.a.
2P	1.02	0.97	+ 0.05	0.15
3P	0.92	0.97	- 0.05	0.15
9T	2.84	0.94	+ 1.90	0.14
1B	1.69	0.93	+ 0.76	0.14
4N/5N	0.80	0.74	+ 0.06	0.11
R4B	1.11	0.89	+ 0.22	0.13
5S	1.43	0.88	+ 0.55	0.13
2I	0.84	0.80	+ 0.04	0.12
13B	2.22	0.77	+ 1.45	0.12
2N	0.98	0.86	+ 0.12	0.13

With the aim of evaluating the vocal effort for occupational purposes, the parameter equivalent Sound Pressure Level (SPL_{eq}, dBA) [14] referred to the distance of 1 m from the source has been evaluated starting from the parameter SPL @ 1m provided by the Vocal Holter device. The obtained results, which refer to the professors that held two lessons, are reported in Fig. 1, where the top chart refers to female subjects while the bottom chart refers to male subjects. For each professor, the parameter SPL_{eq} obtained during the baseline (green bar) and the two lessons (yellow and blue bars) are provided. In the same figure, the levels defined in the international standard ISO 9921:2003 [9] to relate the vocal effort to the SPL_{eq} are shown, which are: normal (below 66 dBA), raised (66 dBA $\leq SPL_{eq} <$ 72 dBA), loud (72 dBA $\leq SPL_{eq} <$ 78 dBA), very loud (above 78 dBA). As expected, the vocal effort increases during the lessons and for all the subjects apart from 06F, 06M, and 09M it passes from normal to raised and for the subjects 07M and 08M approaches the loud level. One should note that the level remains normal also during lessons for professors 06F, 06M and 09M and the second lesson for the professor 00M, who held their lessons in good classrooms (green frame around the professor ID in Fig. 1) according to the considerations summarized in Tab. 4. This is a first important indication of the effects of classroom acoustics on the vocal effort.

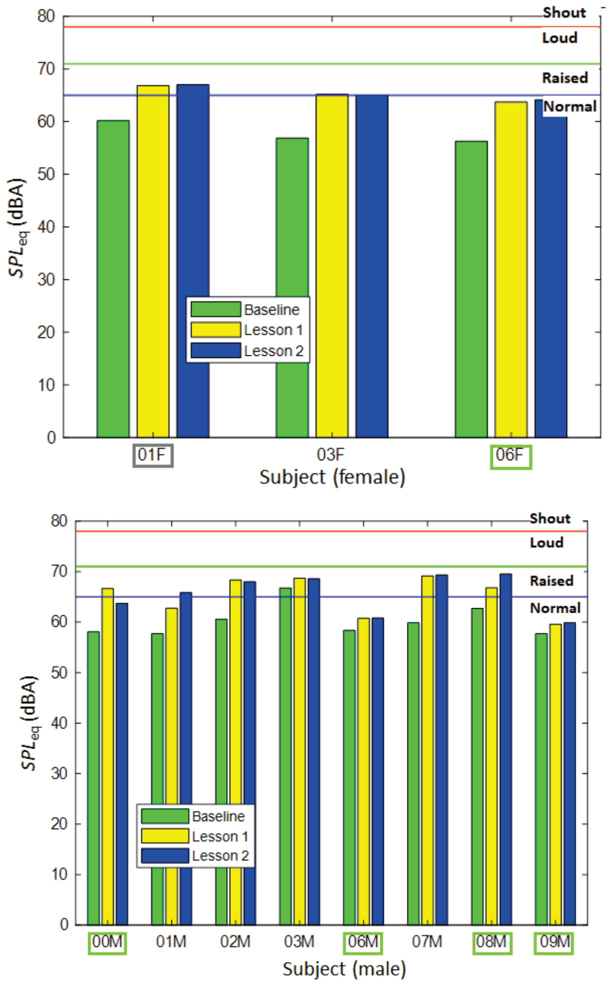

Figure 1. Obtained results for the parameter SPL_{eq} (dBA) @ 1 m for female (top chart) and male (bottom chart) professors who held two lessons; a green frame around the professor ID identifies a classroom qualified as "good".

An evaluation of the effect of classroom acoustics on the vocal effort that involves all the monitored professors has been performed through the parameter ΔSPL_{eq}, which is the difference between the equivalent sound pressure level measured during the lessons and the same parameter measured at the baseline. Subdividing the involved subjects into two classes according to the classroom quality (see Tab. 4), the obtained results for the parameter ΔSPL_{eq} are:

- bad classes (n. 13): $\Delta SPL_{eq,mean}$ = +6.6 dBA, standard deviation of the mean = 0.8 dBA;
- good classes (n. 10): $\Delta SPL_{eq,mean}$ = +4.9 dBA, standard deviation of the mean = 0.8 dBA.

This outcome also confirms the negative impact of bad classroom acoustics on the vocal effort of the monitored professors.

In order to further investigate the effects of classroom acoustics on the behavior of the monitored professors, the mean value of the Sound Pressure Level (SPL_{mean}, dB) during each lesson has been considered. In particular, the difference ΔSPL_{mean} between each lesson and the baseline has been evaluated, thus obtaining an indication that is exempt from personal vice level and that can be compared among the involved subjects. The obtained results are reported in Fig. 2 with respect to the reverberation time T_{20} of each classroom and in Fig. 3 with respect to the parameter ΔBNL_LAF90 (dBA), which represents the difference between lessons and baseline of the Background Noise Level expressed as the A-weighted sound pressure level that is exceeded for 90% of the monitored interval.

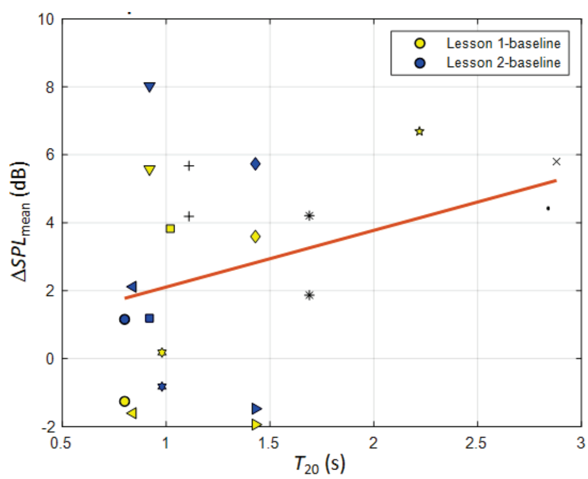

Figure 2. Relationship between ΔSPL_{mean} and T_{20} for all the monitored professors.

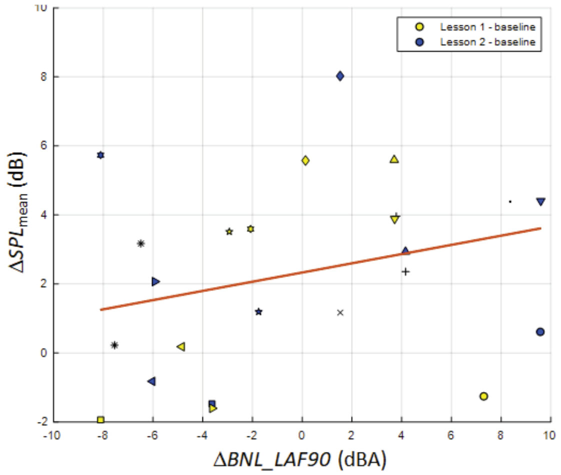

Figure 3. Relationship between ΔSPL_{mean} and ΔBNL_LAF90 for all the monitored university professors.

In both figures, each symbol identifies a professor, and the yellow (blue) color refers to the difference between lesson 1 (lesson 2) and baseline. The two figures also report a straight line that has been obtained by means of a linear fitting of the experimental data, whose slope is of about +1.7 dB/s for the relationship between ΔSPL_{mean} and T_{20} and of about +0.13 dB/dBA for the relationship between ΔSPL_{mean} and ΔBNL_LAF90. Even though these preliminary results do not allow a full statistical qualification of the obtained outcomes, mainly due to the low number of involved subjects and the large spread that can be observed in Figs. 2 and 3, they highlight the importance of a suitable acoustic design of the university classrooms if the goal is the minimization of the vocal effort of professors.

4. CONCLUSIONS

This work summarizes the methodology and results of an experimental campaign of voice monitoring among university professors, who belong to the category that suffer most from voice pathologies (at several grades of severity) due to the use of voice as a primary working tool. Fourteen university professors were involved in the study, being monitored in terms of voice production during their lessons that took place in 13 different university classrooms, which slightly varied in dimensions (i.e., max number of students accepted), presence/absence of acoustical treatment and floor location. Voice monitorings were done by means of the Vocal Holter device, which is a non-intrusive and well-accepted tool capable of detecting voice parameters related to occupational use and health with high accuracy. University classrooms were acoustically characterized in terms of reverberation time and background noise level, so that the voice parameters estimated from the monitorings could then be correlated with them.
Studies have highlighted the need of exploring the extent to which voice adapts to the acoustic environment (e.g., short/long reverberation time, low/high environmental noise) as well as to the amount of time and repetition along several days for which it is used. Therefore, four main findings can be recalled as main outcomes of the present work, that are:

- "Need of detecting the presence of vocal diseases in university professors who underwent a repeated vocal monitoring during their lessons" > four subjects out of the 14 involved exhibited voice parameters that can be considered as pathological, therefore should undergo a medical assistance in order to understand more at a physiological level. The other subjects either resulted in borderline evaluations (e.g., some parameters were within the accepted values, other not) or in healthy evaluations;
- "Possibility to establish warning scores to be assigned to the monitored lessons in order to alert the occupational health service of the university whether it would be worth providing support for the reduction of the related occupational risks" > this work presents the development of a methodology for the definition of a warning score for the monitored subjects, based on the results of parameters obtained from the vocal monitoring (i.e., jitter, shimmer, CPPS). The aim of this warning score is the identification of possible vocal diseases and thus the need of a specialist health surveillance;
- "Extension of the understanding of whether the measured voice parameters depend on classroom acoustics" > to the aim of the present study, the measured reverberation time in each considered classroom has been considered as the most important qualifier. Based on this, a comparative analysis with the parameter ΔSPL_{eq} (which is the difference between the equivalent sound pressure level measured during the lessons and the same parameter measured at the baseline) and the parameter ΔSPL_{mean} (which is the difference between the mean value of the sound pressure level measured during the lessons and the same

parameter measured at the baseline), was performed and confirmed the negative impact of bad classroom acoustics (i.e., long reverberation time) on the vocal effort of the monitored professors;

- "Corroboration of the analyses pertaining to the differences in voice production of university professors during the working activity with respect to a conversational activity" > thanks to the evaluation of the ΔSPL_{eq} and the ΔSPL_{mean} it has been possible to set both the evaluation of the effect of classroom acoustics on the vocal effort and the elimination of bias due to subjective voice level. Results demonstrate that the vocal effort increases during the lessons and for all the subjects apart from the ones who held their lessons in classrooms with good acoustic conditions.

Limitations exist on the presented study, particularly with respect to (i) the dimension of the university professors' sample involved, which should be extended primarily to reduce the across-subjects variability of voice results, and to (ii) the variety of university classrooms considered, as the room acoustics properties correlated to the voice parameters did not range across very different values. However, the methodology proposed is robust in terms of repeatability and accuracy of results; therefore, it can be used for future experimental campaigns that should be designed to fill in the lacks of the available comparative studies.

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